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EXPERIMENTAL DETERMINATION OF RESIDUAL MOLDED-IN  
STRESS LEVEL IN PLASTIC ROTATING BANDS

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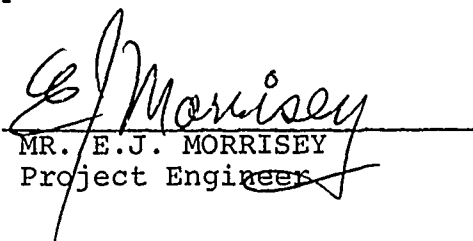
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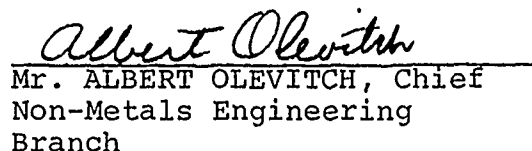
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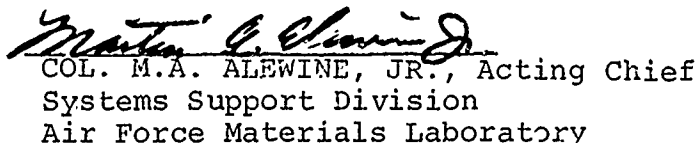
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Polyethersulfone (PES) has been investigated for use as an injection molded rotating band material on 20 mm projectiles. Molded bands have been observed to develop crazing when exposed to solvent laden atmospheres. The presence of residual stresses resulting from thermal contraction during cool-down and melt stresses in the polymer on filling the cavity exacerbate this stress cracking problem. The purpose of this investigation was			

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to experimentally establish the magnitude of this residual molded-in stress level. Tensile specimens of PES were subjected to solvent induced stress-rupture tests in a laboratory test set-up. A relationship between both the time-to-craze and the time-to-failure and the applied stress was developed over the stress range of 500 to 5000 psi. Three different solvents were used to encompass this wide stress range within reasonable testing times. After this relationship between tensile stress and time-to-craze was established, actual projectiles were immersed in the solvents and the time-to-craze recorded. Correlation of the projectile test results with the tensile test results indicated that the residual molded-in stress in the rotating bands was 1750  $\pm$  800 psi (12.06  $\pm$  5.51 MPa). ←

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## PREFACE

This report covers work performed during the period from January to April 1978 under Air Force Contract F33615-78-C-5002, Project Number 7381. The work was administered under the direction of the Systems Support Division of the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio. Mr. Edward J. Morrissey (AFML/MXE) acted as project engineer.

The principal investigator on this investigation was D. Robert Askins. The major portion of the laboratory work was conducted by L. Dee Pike, senior research technician.

This report was submitted by the author in October 1978. The contractor's report number is UDR-TR-78-73.

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## SECTION I

### INTRODUCTION

The use of injection molded thermoplastics for rotating band applications on both small and large bore ammunition has been under investigation for several years. One of the materials currently being utilized in this regard on 20 mm projectile is polyethersulfone (PES). Bands made of this material possess many desirable features. One problem area which has been observed, however, involves solvent resistance. Molded bands have been observed to develop crazing when exposed to solvent (ethyl acetate) laden atmospheres. The presence of residual stresses resulting from thermal contraction during cool-down and melt stresses in the polymer on filling the cavity aggravate this stress cracking problem. The purpose of this investigation was to establish the magnitude of this residual molded-in stress level.

Tensile specimens of PES were subjected to solvent-induced stress-rupture tests and a relationship between applied stress and both time-to-craze and time-to-failure was developed. After this relationship between tensile stress and time-to-craze was established, actual projectiles with molded PES rotating bands were immersed in solvent and the time-to-craze recorded. Correlation of the projectile test results with the tensile specimen test results were then made to develop an estimate of the residual molded-in stress in the rotating bands.

Finally, a solvent resistant coating was applied to a number of tensile stress-rupture specimens in an effort to reduce the susceptibility of PES to solvent-induced stress cracking.

## SECTION II

### SPECIMEN PREPARATION

Two types of specimens were utilized in this investigation. The first was an injection-molded 8.5 inch (21.6 cm) long tensile specimen whose dimensions corresponded to that prescribed in ASTM D638, Type I. Overall specimen length was 8.5 inches (21.6 cm). Specimen thickness was  $0.135 \pm 0.005$  inch ( $0.343 \pm 0.013$  cm). This specimen type was injection molded on a Newbury-Eldorado Model 3V-75RS injection molding machine with the following machine operating conditions:

TABLE 1  
INJECTION MOLDING CONDITIONS

Nozzle Temperature	700°F (371°C)
Front Barrel Temperature	715°F (379°C)
Rear Barrel Temperature	675°F (357°C)
Mold Temperature	300°F (149°C)
Injection Pressure	1500 psi (10.32 MPa)
Back Pressure	250 psi (1.72 MPa)
Injection Time	15 seconds
Open Time	60 seconds
Overall Cycle Time	180 seconds
Ram in Motion Time	2-3 seconds
Screw Speed	50 RPM
Part Shot Size	1.5 oz.

The mold was side-gated in one of the specimen grip sections. Prior to molding, the resin was dried overnight at 325°F (163°C). After molding, the specimens were annealed to relieve residual molded-in stresses. Specimens were annealed by placing them in a R.T. air circulating oven, raising the temperature to 380°F (193°C), holding this temperature for 18 hours, then turning off heat but allowing the air to circulate and cooling to 150°F (66°C) before removal. Examination of specimens under cross-polarized light indicated that annealing did reduce the residual stress levels, but also that even in the unannealed condition, the residual stresses in the tensile specimens were quite low to start with (on the order of a few hundred psi at most).

The second type of specimen was an actual rotating band molded onto a 20 mm projectile (Figure 1). These specimens were molded by AVCO<sup>1</sup> and provided to us for this investigation. The bands were injection molded with two tunnel or submarine gates diametrically opposed to each other. After molding, a roughened imperfection on the band surface was observed at the gating locations.

In the final phase of the investigation, in which the effect of a coating on solvent stress cracking behavior was examined, 6 inch (15.2 cm) long tensile specimens (ASTM D638, Type I) were molded and provided by ICI<sup>2</sup>. All of the dimensions of these specimens were identical to those of the longer specimen described above except for the length of the two gripping sections. These specimens were not annealed. Two coatings were evaluated, one blue and another yellow. Both the blue and yellow paints corresponded to TT-E-516, composition L (alternatively TT-E-515, composition L). The yellow was color number 33538 and the blue was color number 25109, both per Federal Standard 595. The coatings were applied by AVCO and to our knowledge differ only in pigment.

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<sup>1</sup>AVCO Corp., Wilmington, Massachusetts.

<sup>2</sup>ICI United States, Inc., Wilmington, Delaware.



Figure 1. Plastic Rotating Band Specimen. (Note imperfection at gate location where excess material was trimmed.)

### SECTION III

#### STRESS CRACKING TEST PROCEDURES

Specimens for tensile stress-rupture tests were sealed in a test tube with a slot cut into the bottom (Figure 2). The seal around the specimen passing through the slot was achieved with RTV 118 silicone rubber adhesive/sealant. After mounting of this specimen/tube assembly in a creep machine (Figure 3), taking care to insure accurate axial alignment, the specimen was loaded to the desired stress level. The solvent was then introduced as rapidly as possible into the test tube, taking care not to splash into the gripped area. When the tube had been filled (a process requiring about three seconds), the time-to-craze and time-to-failure counts were started.

Projectile rotating band specimens for solvent stress cracking tests were placed in a small beaker and brightly illuminated with several high intensity microscope lights. Opposite sides of the rotating bands were observed through two telescopes. When the lighting was set and the telescopes focused on the band, the solvent was rapidly introduced into the beaker and the time count to the appearance of the first craze started. During this observational period, the projectile was slowly rotated by hand so that the two observers could continuously inspect the entire circumference.



Figure 2. Tensile Stress Cracking Specimen Sealed in Test Tube.

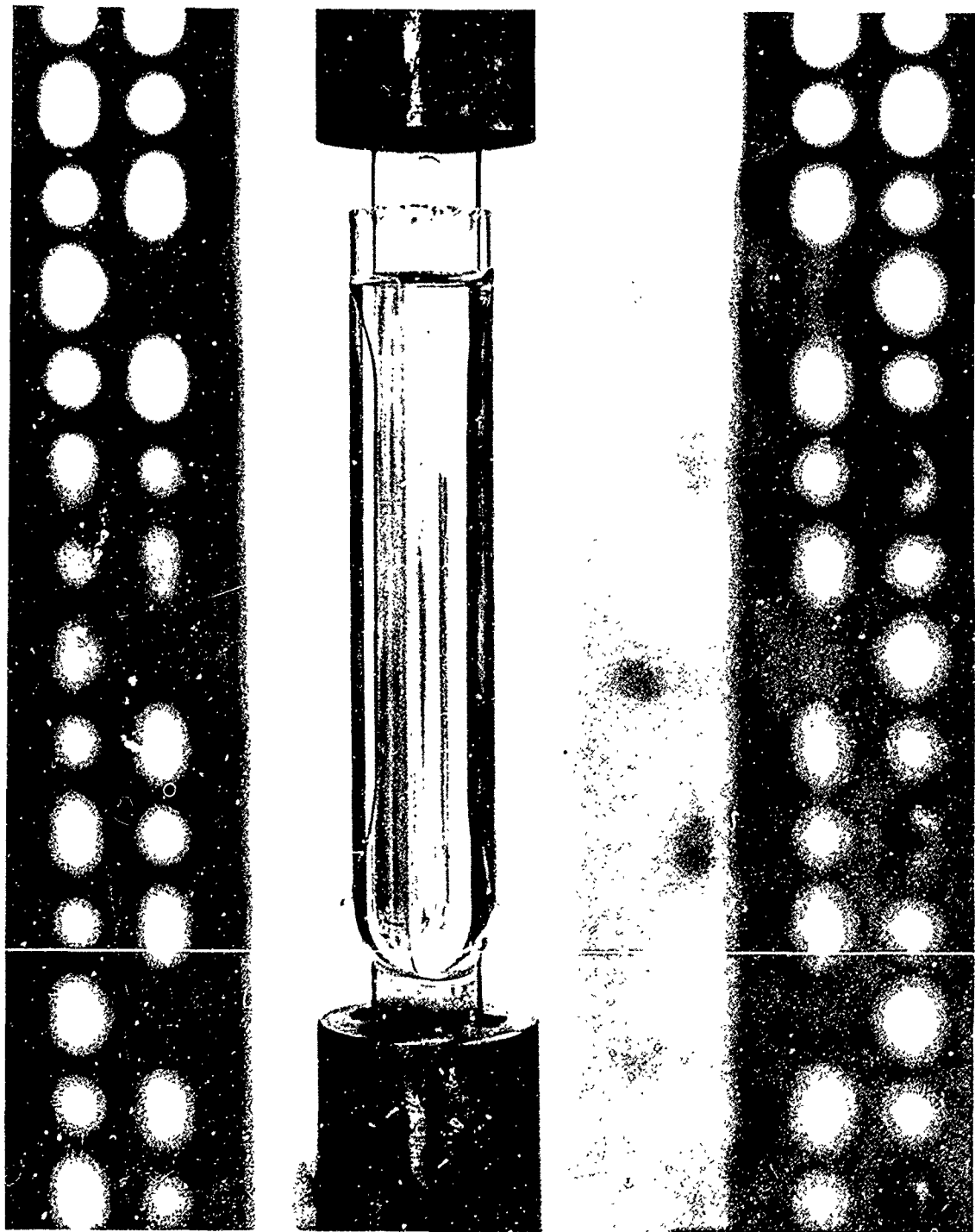


Figure 3. Tensile Stress-Rupture Specimen Immersed in Solvent and Under Load.

## SECTION IV

### DISCUSSION OF RESULTS

#### 1. RESIDUAL STRESS LEVEL

For each tensile stress-rupture specimen described in Section III and illustrated in Figures 2 and 3, two times were recorded; (1) the time elapsed until the first craze appeared, and; (2) the time elapsed until total fracture. This information was desired over the stress range of 500 to 5000 psi (3.45 to 34.45 MPa). The use of three different solvents was required in order to develop time-to-craze/fracture vs. applied stress data over this entire stress region in convenient time periods. Methoxy-ethanol was used in the low stress region (500-2500 psi or 3.45-17.23 MPa), acetic acid in the midrange (1500-3500 psi or 10.34-24.12 MPa), and isopropanol in the high stress region (3000-5000 psi or 20.67-34.45 MPa). Table 2 presents the results of these tests. Figures 4-9 present these data in graphical form.

Figure 10 illustrates typical crazes which occurred in the rotating band specimens tested as described in Section III. Only crazing could be observed on these rotating band specimens, not total failure as with the tensile specimens. Presumably, as crazing occurred, the hoop stresses were relieved and no stresses remained to cause complete fracture. In every case, the crazes which occurred on the rotating band specimens occurred at the two gating locations and also at the two "weld" lines located midway around the band between the two gates. Table 2 lists the observed time-to-craze for each of the projectile specimens tested.

In order to estimate the residual molded-in stress in the PES rotating bands, the time-to-craze for the bands was compared to the time-to-craze for the tensile specimens. These comparisons are presented graphically in Figures 4-6. Since the rotating band specimens immersed in isopropanol had not crazed in 30 hours, it would appear, from Figure 4, that the residual stress

TABLE 2  
POLYETHERSULFONE TENSILE STRESS CRACKING BEHAVIOR

Stress		Time to Craze	Time to Fracture	Time to Craze	Time to Fracture	Time to Craze	Time to Fracture
(psi)	(MPa)	Isopropanol		Acetic Acid		Methoxyethanol	
5000	34.45	1.4 M 0.5 M 0.4 M	<3.3 H 1 H 0.6 H				
4500	31.01	3.25 M 0.7 M 0.6 M	3.7 H 2.5 H 2 H	instant	45 s		
4000	27.56	5.5 M 9 M 4.5 M	13.9 H 16.2 H 8.4 H				
3500	24.12	0.5-1.0 H 44 M 42 M	97 H 70.1 H 73.5 H	7 s	0.09 H		
3000	20.67	72 H	>460 H	12 s	0.1 H		
2500	17.23	>150 H		40 s 45 s	0.24 H 0.23 H	5 s 3 s 2 s	15 s 18 s 20 s
2000	13.78	>76 H		45 s 60 s 65 s	0.3 H 0.36 H 0.75 H	5 s 15 s 7 s 6 s 3 s	25 s 45 s 45 s 20 s 29 s
1500	10.34	>76 H		60 s 306 s 60 s 65 s	2.7 H 2.43 H 0.78 H 2.32 H	10 s 20 s 10 s 7 s 5 s	75 s 70 s 20 s 20 s 22 s
1000	6.89	>485 H		50 s 6 M 60 s 9 M >189 H	3.94 H 15.5 H >428 H >236 H >189 H	80 s 60 s 15 s 20 s 190 s	465 s 215 s 20 s 25 s 255 s
900	6.20					115 s 80 s 630 s	230 s 288 s 666 s
750	5.17					540 s	1040 s
500	3.45					1040 s	3420 s
Projectile Bands		>30 H >30 H		75 s <120 s 18 s		21 s 10 s 9 s 21 s	

NOTE: Designations - H=hours; M=minutes; s=seconds;  
>=greater than; <=less than.

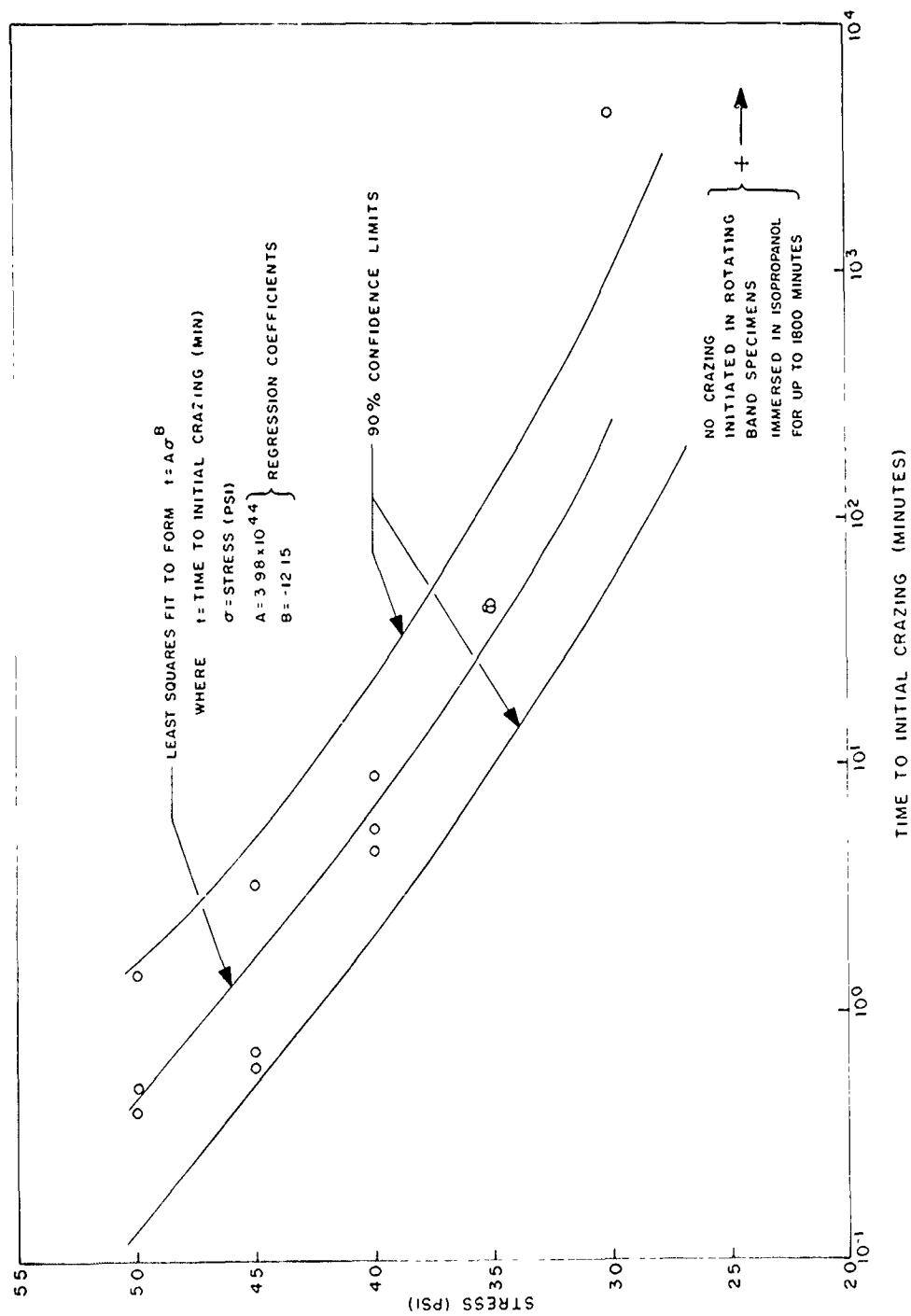


Figure 4. Effect of Stress on Stress Crazing Behavior of Polyethersulfone in Isopropanol.

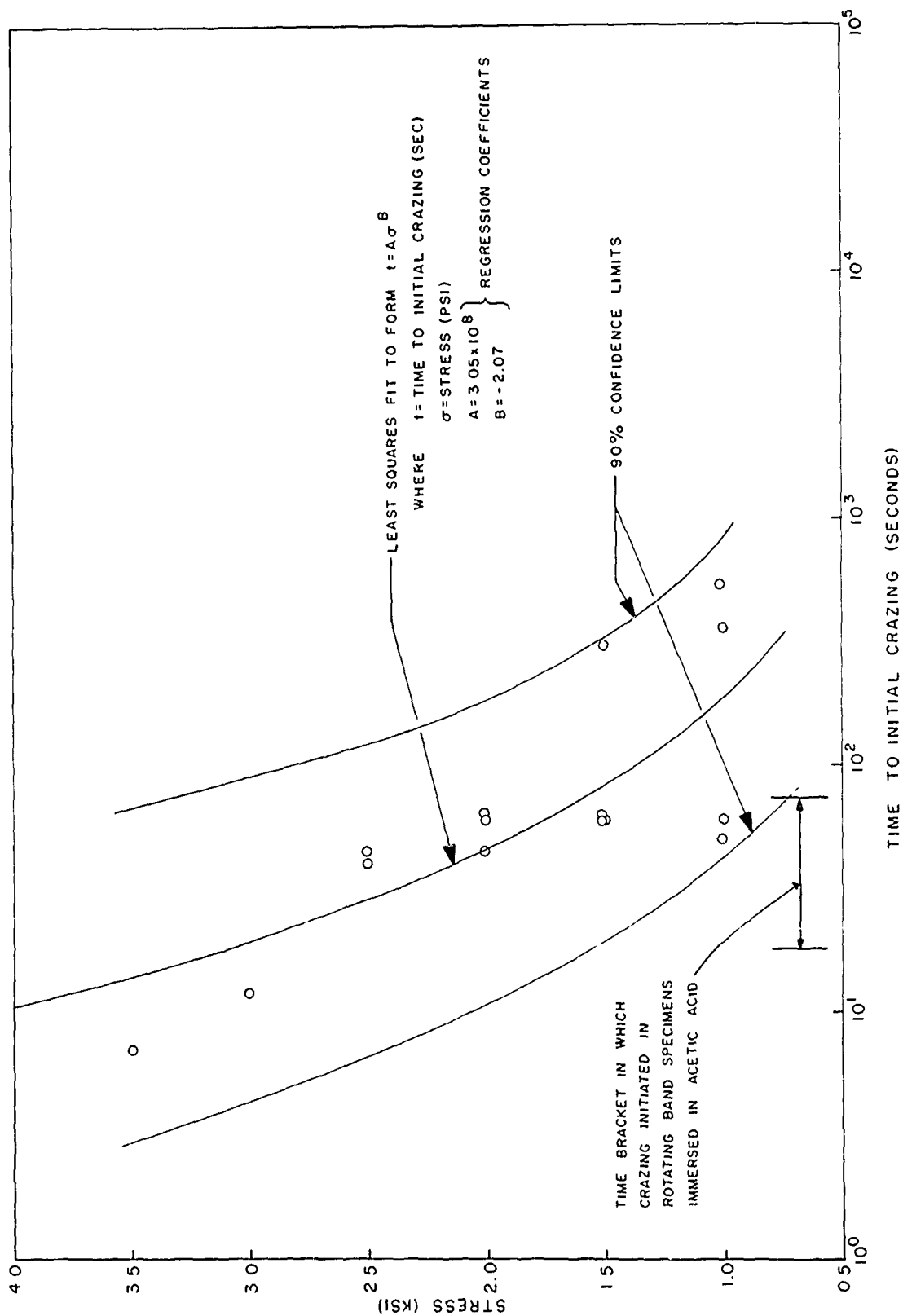


Figure 5. Effect of Stress on Stress Crazing Behavior of Polyethersulfone in Acetic Acid.

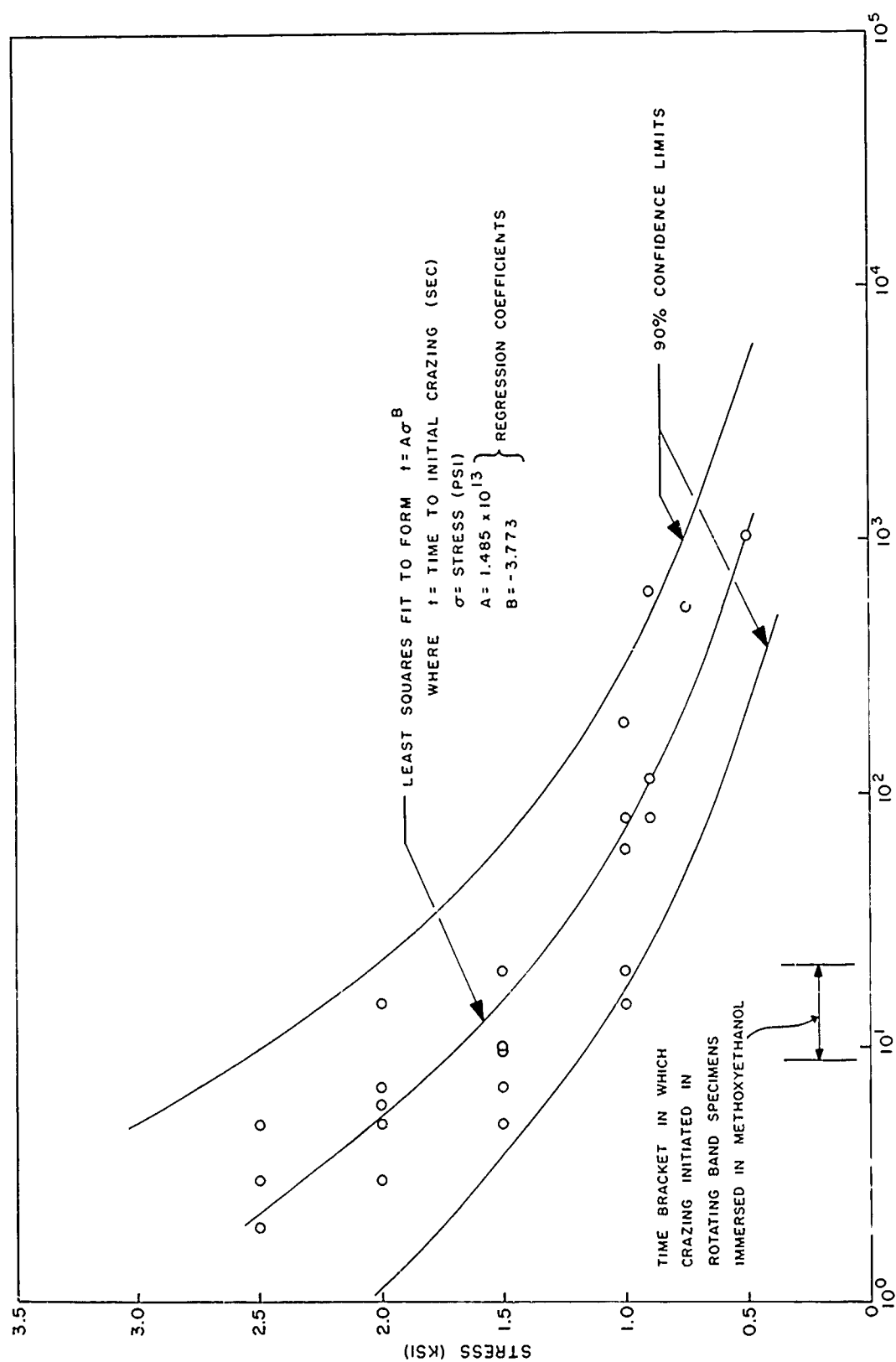


Figure 6. Effect of Stress on Stress Crazing Behavior of Polyethersulfone in Methoxyethanol.

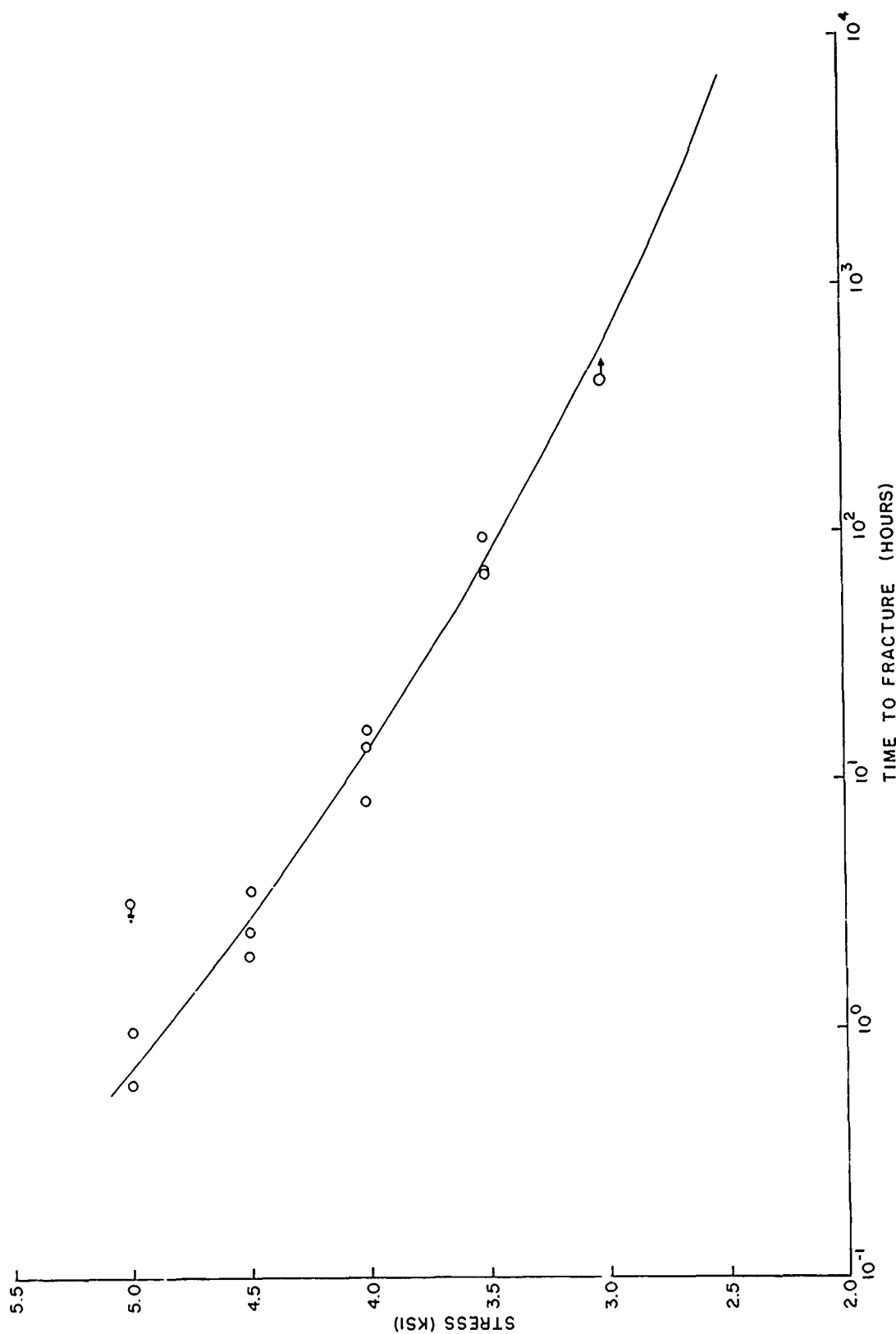


Figure 7. Effect of Stress on Stress Fracture Behavior of Polyethersulfone in Isopropanol.

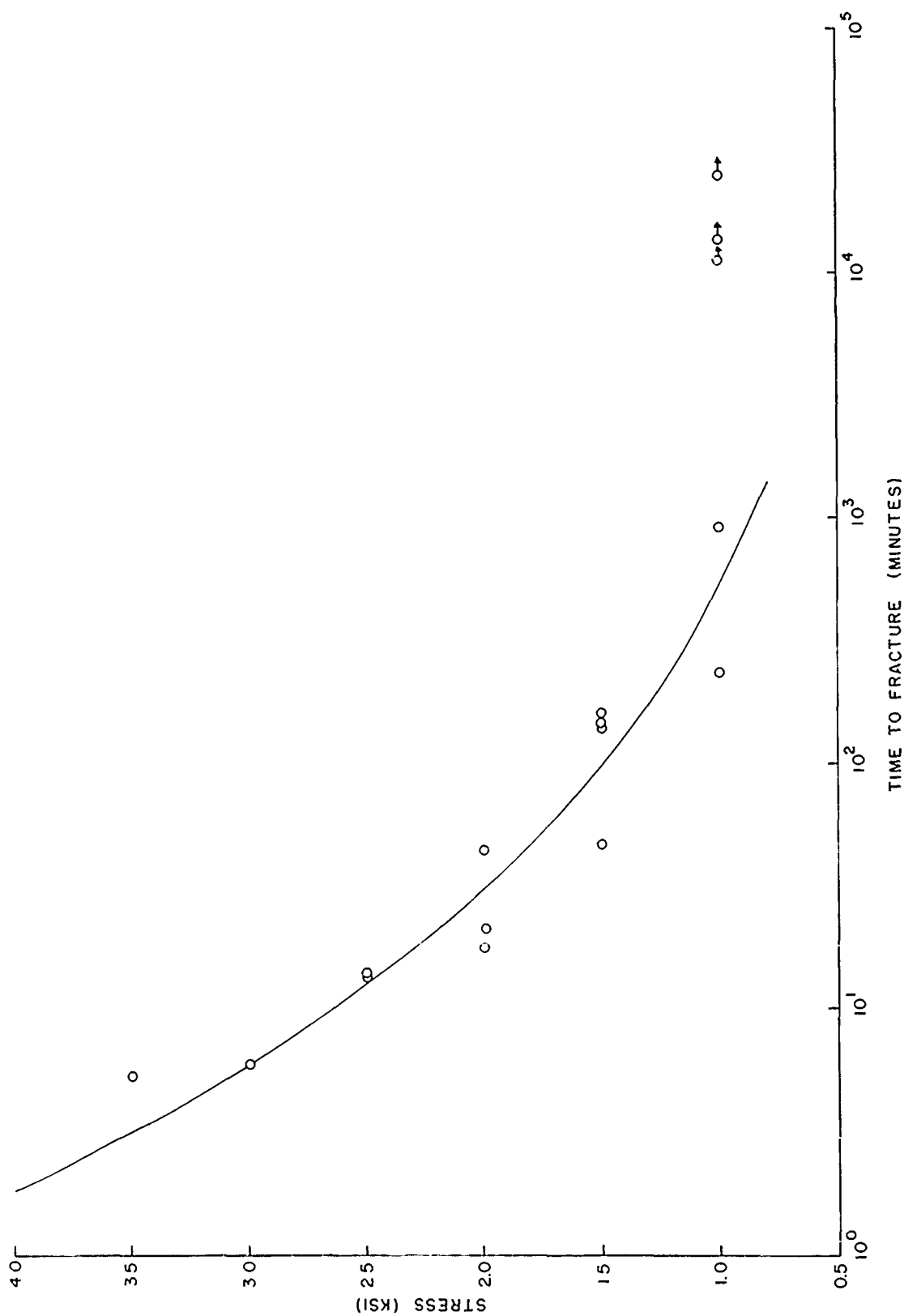


Figure 8. Effect of Stress on Stress Fracture Behavior of Polyethersulfone in Acetic Acid.

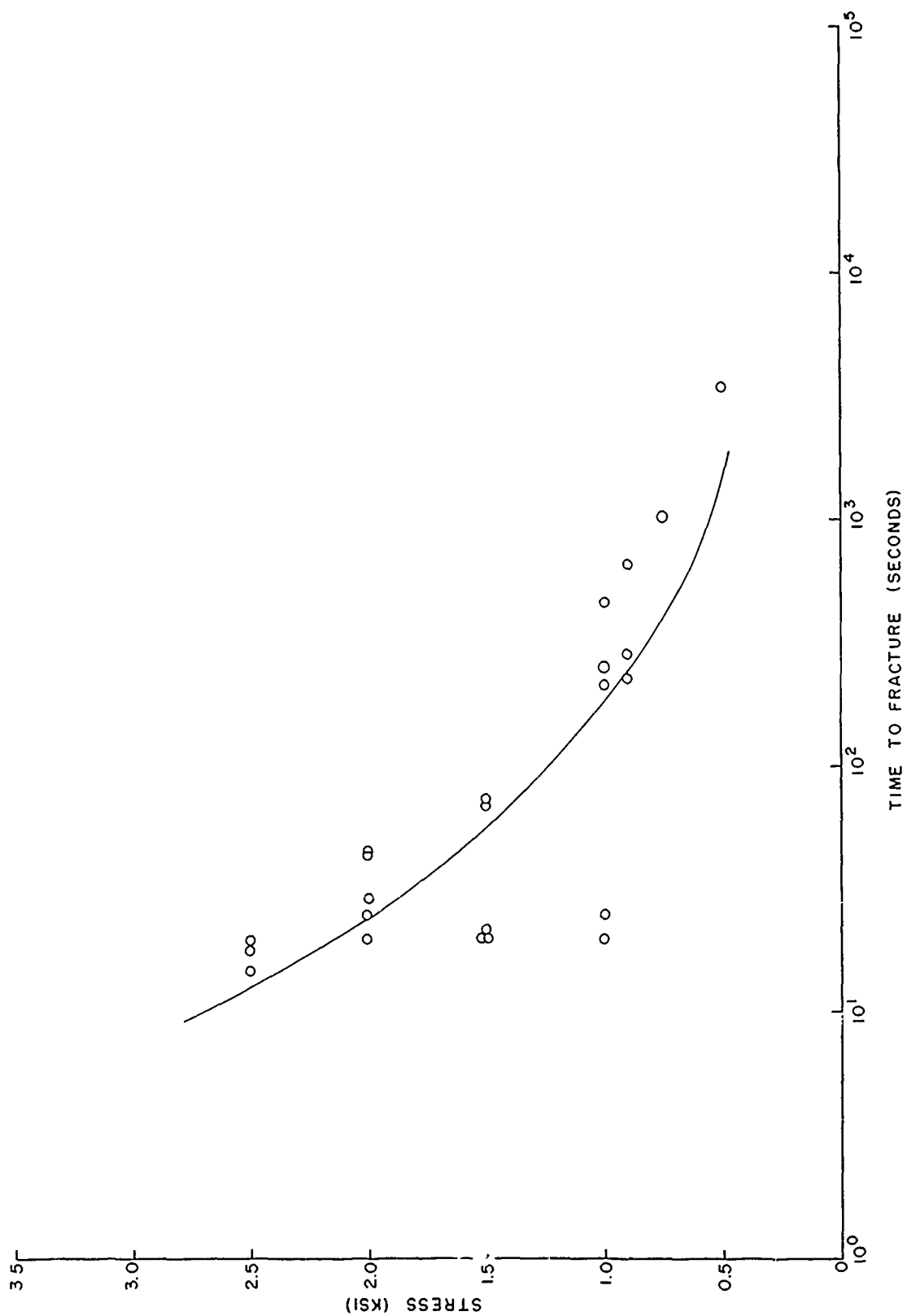


Figure 9. Effect of Stress on Stress Fracture Behavior of Polyethersulfone in Methoxyethanol.

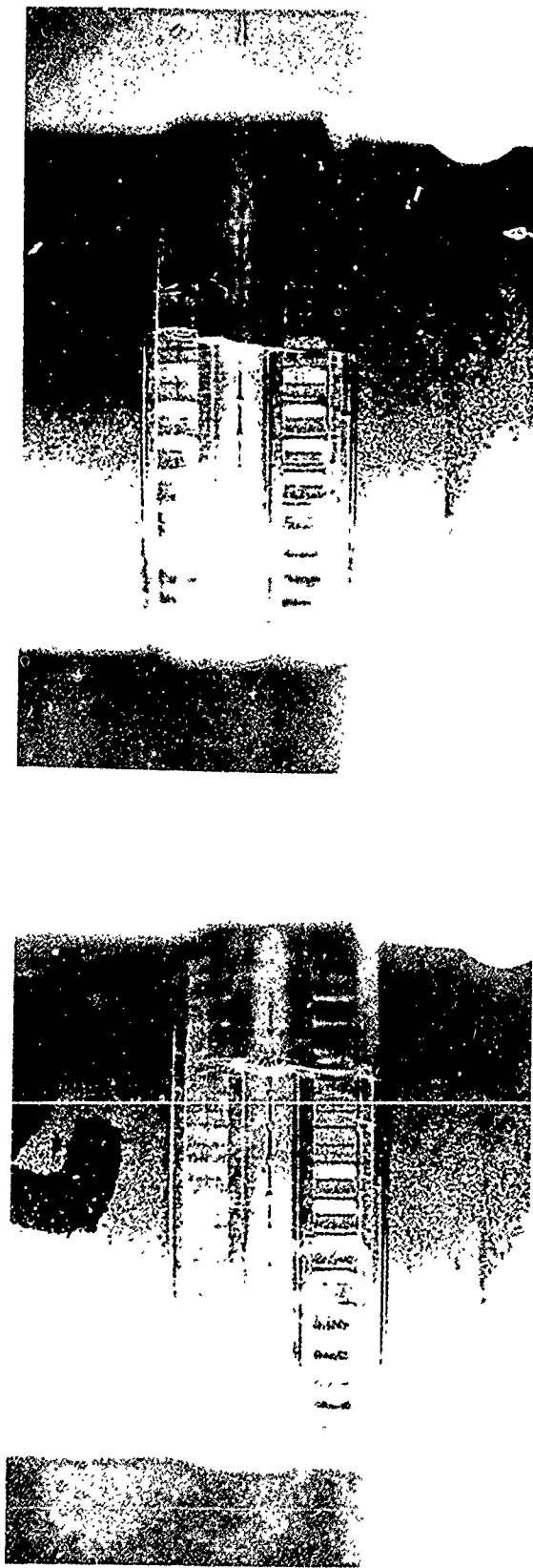


Figure 10. Typical Crazing in PES Rotating Bands on 20 mm Projectiles.

is less than 2850 psi (19.64 MPa). The scatter in the acetic acid crazing data makes it difficult to estimate the residual stress level from the data plotted in Figure 5, although on the low end one could conclude that it was greater than 750 psi (5.17 MPa). The methoxyethanol data, presented in Figure 6, indicates that the residual stress is in the 950-2550 psi (6.55-17.57 MPa) region [ $1750 \pm 850$  psi ( $12.06 \pm 5.51$  MPa)] which is consistent with the isopropanol and acetic acid data, although still more statistically uncertain than one would like. Since the number of specimens, and particularly the rotating band specimens, was limited, it was impossible to obtain a larger statistical sampling and, presumably, a concomitant reduction in scatter and uncertainty.

## 2. EFFECT OF COATINGS ON STRESS CRACKING

The tests to determine the effectiveness of the painted coatings on solvent stress cracking behavior were conducted in the same manner as those described in the first paragraph of Section III except that the shorter ICI molded specimens were used. Two different immersion solvents were used. The first was pure ethyl acetate and the second was a 50/50 mixture, by volume, of ethyl acetate and ethanol. In the pure ethyl acetate, painted and unpainted specimens were stressed to 1000 psi (6.89 MPa) and 2000 psi (13.78 MPa) and immersed in the solvent. In the 50/50 solvent mixture, painted and unpainted specimens were stressed to 4000 psi (27.56 MPa) before immersion. Table 3 presents the results of these tests.

In the pure ethyl acetate, both the blue and yellow paint softened and wrinkled up on the specimens after only a few seconds and shortly thereafter developed multiple pinholes along the corners of the specimen cross section, with this deterioration occurring somewhat more rapidly on the blue paint than on the yellow. In the solvent mixture, the blue paint also started wrinkling almost immediately, while the yellow paint did not start wrinkling until ten minutes after immersion.

TABLE 3  
EFFECT OF PAINT ON TENSILE STRESS CRACKING  
BEHAVIOR OF POLYETHERSULFONE

Stress (psi) (MPa)		Solvent	Time to Fracture (minutes)		
			Unpainted	Blue	Yellow
1000	6.89	Ethyl Acetate ↓	3.0	8.5	22.0
			27.4	8.2	45.6
				18.3	
				1.1	
		Avg.	15.2	9.0	33.8
2000	13.78	Ethyl Acetate ↓	0.48	0.58	0.42
			0.80	0.63	0.65
					2.50
		Avg.	0.64	0.61	1.18
4000	27.56	50/50 Ethyl Acetate/Ethanol ↓	2.43	3.75	15.83
			2.57	4.83	21.67
				4.38	16.50
					16.08
		Avg.	2.50	4.32	17.52

The data in Table 3 indicate that the blue paint as applied to these tensile specimens offers little or no protection to PES in the presence of ethyl acetate. The yellow paint does offer some protection although its tendency to soften and wrinkle would indicate that it is also attacked rather severely by the ethyl acetate solvent.

SECTION V  
CONCLUSIONS

1. The residual molded-in stress level in 20 mm polyether-sulfone rotating bands is in the region of  $1750 \pm 800$  psi ( $12.06 \pm 5.51$  MPa).
2. These residual molded-in stresses are concentrated at the weld lines and gating points on the bands.
3. The yellow paint offers more protection to the PES tensile specimens in the environments tested than the blue paint, which provided little if any benefit over the unpainted PES.

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